

UTILITY PATENT APPLICATION TRANSMITTAL (Small Entity)

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Docket No.
1945/193

Total Pages in this Submission
32

TO THE ASSISTANT COMMISSIONER FOR PATENTS

Box Patent Application
Washington, D.C. 20231

Transmitted herewith for filing under 35 U.S.C. 111(a) and 37 C.F.R. 1.53(b) is a new utility patent application for an invention entitled:

MOBILE X-RAY INSPECTION SYSTEM FOR LARGE OBJECTS

and invented by:

Roderick Swift
Andrew Tybinkowski

If a CONTINUATION APPLICATION, check appropriate box and supply the requisite information:

☒ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 09/072,212

Which is a:

☒ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.: 08/799,533

Which is a:

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Enclosed are:

Application Elements

1. ☒ Filing fee as calculated and transmitted as described below
2. ☒ Specification having 17 pages and including the following:
 - a. ☒ Descriptive Title of the Invention
 - b. ☒ Cross References to Related Applications (if applicable)
 - c. ☐ Statement Regarding Federally-sponsored Research/Development (if applicable)
 - d. ☐ Reference to Microfiche Appendix (if applicable)
 - e. ☒ Background of the Invention
 - f. ☒ Brief Summary of the Invention
 - g. ☒ Brief Description of the Drawings (if drawings filed)
 - h. ☒ Detailed Description
 - i. ☒ Claim(s) as Classified Below
 - j. ☒ Abstract of the Disclosure

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Application Elements (Continued)

3. ☒ Drawing(s) *(when necessary as prescribed by 35 USC 113)*
a. ☒ Formal b. ☐ Informal Number of Sheets 5
4. ☒ Oath or Declaration
a. ☐ Newly executed *(original or copy)* ☐ Unexecuted
b. ☒ Copy from a prior application (37 CFR 1.63(d)) *(for continuation/divisional application only)*
c. ☐ With Power of Attorney ☐ Without Power of Attorney
d. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s) named in the prior application,
see 37 C.F.R. 1.63(d)(2) and 1.33(b).
5. ☐ Incorporation By Reference *(usable if Box 4b is checked)*
The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied under
Box 4b, is considered as being part of the disclosure of the accompanying application and is hereby
incorporated by reference therein.
6. ☐ Computer Program in Microfiche
7. ☐ Genetic Sequence Submission *(if applicable, all must be included)*
a. ☐ Paper Copy
b. ☐ Computer Readable Copy
c. ☐ Statement Verifying Identical Paper and Computer Readable Copy

Accompanying Application Parts

8. ☐ Assignment Papers *(cover sheet & documents)*
9. ☐ 37 CFR 3.73(b) Statement *(when there is an assignee)*
10. ☐ English Translation Document *(if applicable)*
11. ☐ Information Disclosure Statement/PTO-1449 ☐ Copies of IDS Citations
12. ☐ Preliminary Amendment
13. ☒ Acknowledgment postcard
14. ☒ Certificate of Mailing
☐ First Class ☒ Express Mail *(Specify Label No.):* EM529201055US

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Accompanying Application Parts (Continued)

15. ☐ Certified Copy of Priority Document(s) (if foreign priority is claimed)
16. ☒ Small Entity Statement(s) - Specify Number of Statements Submitted: 1 (from prior application)
17. ☐ Additional Enclosures (please identify below):

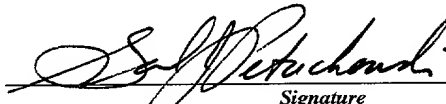
Fee Calculation and Transmittal

CLAIMS AS FILED

For	#Filed	#Allowed	#Extra	Rate	Fee
Total Claims	1	- 20 =	0	x \$9.00	\$0.00
Indep. Claims	1	- 3 =	0	x \$39.00	\$0.00
Multiple Dependent Claims (check if applicable) <input type="checkbox"/>					\$0.00
BASIC FEE					\$380.00
OTHER FEE (specify purpose)					\$0.00
TOTAL FILING FEE					\$380.00

- ☒ A check in the amount of \$380.00 to cover the filing fee is enclosed.
- ☒ The Commissioner is hereby authorized to charge and credit Deposit Account No. 19-4972 as described below. A duplicate copy of this sheet is enclosed.
- ☐ Charge the amount of as filing fee.
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- ☒ Charge any additional filing fees required under 37 C.F.R. 1.16 and 1.17.
- ☐ Charge the issue fee set in 37 C.F.R. 1.18 at the mailing of the Notice of Allowance, pursuant to 37 C.F.R. 1.311(b).

Dated: May 5, 1999


Signature

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cc:

**VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS -
SMALL BUSINESS CONCERN**

Applicant(s): Roderick Swift
Andrew Tybinkowski

Serial No: 08/799,533

Date Filed: February 12, 1997

For: MOBILE X-RAY INSPECTION SYSTEM FOR LARGE OBJECTS

I hereby declare that I am an official of the following small business concern and am empowered to act on its behalf:

American Science and Engineering, Inc.
825 Middlesex Turnpike
Billerica, MA 01821

I hereby declare that the above-identified small business concern qualifies as a small business concern as defined in 13 CFR 121.3-18, and reproduced in 37 CFR 1.9(d), for purposes of paying reduced fees under Section 41(a) and (b) of Title 35, United States Code, in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average over the previous fiscal year of the concern of the persons employed on a full-time, part-time, or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third-party or parties controls or has the power to control both.

I hereby declare that rights under contract or law have been conveyed to, and remain with, the small business concern identified above with regard to the above-referenced invention.

If the rights held by the above-identified small business concern are not exclusive, each individual, concern, or organization having rights to the invention is listed below and no rights to the invention are held by any person, other than the inventor(s), who would not qualify as an independent inventor under 37 CFR 1.9(c) if that person made the invention, or by any concern which would not qualify as a small business concern under 37 CFR 1.9(d) or a nonprofit organization under 37 CFR 1.9(e).

I acknowledge the duty to file, in this application, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the

[illegible]

FOR

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Mobile X-Ray Inspection System for Large Objects

5 The U.S. Government may have a paid-up license in portions of this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided by the terms of Contract No. N39998-97-C-5209 awarded by the U.S. Department of the Navy, and Grant No. 93-G-003 awarded by the U.S. Department of Transportation, Federal Aviation Administration.

10 The present application is a continuation of U.S. patent application, serial no. 09/072,212, filed May 4, 1998, currently allowed, itself a continuation of serial no. 08/799,533, filed February 12, 1997, issued as U.S. Patent no. 5,764,683, all of which are incorporated herein by reference. The present application claims priority from U.S. provisional application number 60/011,495, filed February 12, 1996, also incorporated herein
15 by reference.

Field of the Invention

 The present invention relates to the inspection of large containers by means of x-ray radiation, and more particularly to the x-ray inspection of cargo containers by means of
20 transmitted and back scattered radiation.

Background Art

 The interdiction of illicit drugs, explosives, and other contraband is an important goal of law enforcement. To that end, a variety of technologies have been developed and deployed
25 for the non-intrusive inspection of containers not readily susceptible to visual scrutiny from the outside. The non-intrusive aspect of these inspection techniques is important; the great majority of containers do not carry contraband, and the public would not long tolerate the delays, disruption (and in some cases damage) of property, and invasions of privacy that would occur if invasive inspection means were commonly used. Non-intrusive inspection is

typically non-destructive and can usually be accomplished faster than intrusive inspection, thereby increasing productivity of inspectors. Increased productivity means more containers inspected and more contraband interdicted.

Among non-intrusive inspection methods, x-ray imaging in its many forms has been a proven technology capable of detecting a variety of contraband. X-ray systems have been based on transmission imaging in any of a variety of implementations: cone-beam (fluoroscopes), fanbeam, flying-spot, multi-projection configurations; dual-energy imaging; computed tomography; as well as on imaging incorporating the detection of x-ray radiation scattered in various directions.

With only a few exceptions, x-ray imaging systems for contraband detection have operated within the source-energy range of 70 keV to 160 keV. Since the penetrating power of these sources is limited, inspection is limited to relatively small parcels and containers. A few large, expensive, high-energy transmission imaging systems have also been built for the inspection of large containers or vehicles. These systems typically operate within the range of 6 MeV to 12 MeV, require heavily-shielded, fixed installations, and provide no means to distinguish organic materials.

Radiant energy imaging with a scanning pencil beam is the subject of United States patent 3,780,291. The creation and use of images from scattered x-radiation in conjunction with direct transmission images is the subject of United States patent 5,313,511. These patents are hereby incorporated herein by reference. Neither of the foregoing references, nor any prior art known to the inventors herein, discloses or suggests how x-ray images, in a sense defined below, may be formed of cargo containers on the scale of motor vehicles or railroad cars using a source of penetrating radiation and detectors mounted on a mobile platform.

Summary of the Invention

The current invention extends the role of inspection by penetrating radiation to encompass large containers and over-the-road vehicles, and at the same time retains the

advantages of discriminating among materials as provided by backward, forward, or sideward scatter imaging.

In a preferred embodiment, the invention provides a device for inspecting a cargo container with penetrating radiation. The device of this embodiment has a bed moveable
5 along a first direction having a horizontal component, a source of penetrating radiation, mounted on the bed, for providing a beam, a motorized drive for moving the bed in the first direction, and at least one detector mounted on the bed and having a signal output so that the beam is caused to traverse the cargo container as the bed is moved and each detector provides a signal for characterizing the cargo container and any contents of the cargo container. In
10 further embodiments of the invention, the source of penetrating radiation may be an x-ray source, and the at least one detector may be a backscatter detector, a transmission detector, a sidescatter detector, or a forward scatter detector. The beam may be a pencil beam scanned repeatedly along a second direction having a vertical component.

In a further embodiment, the device also has a boom, movably linked to the bed. The
15 boom has a storage position, substantially fixed with respect to the bed, and an operation position that is transverse to the first direction, as well as an end region. A beam catcher is attached to the end region of the boom for impeding the further passage of penetrating radiation in the second direction when the boom is in the operation position. The back scatter detector has upper and lower elements, the upper element being movably mounted with
20 respect to the lower element, so that in a first position the upper element is transversely disposed with respect to the lower element and in a second position the upper element is substantially collinear with respect to the lower element. The source of penetrating radiation may provide a pencil beam that is scanned repeatedly over an angle of regard, the angle having an orientation with respect to the horizontal, and the device also includes a steering
25 arrangement for steering the orientation of the angle of regard with respect to the horizontal.

Instead of fitting the boom with a beam catcher, the boom may be alternatively provided, at its end region, with a transmission detector attached to respond to penetrating radiation transmitted through the container, so as to provide a signal for forming a transmission image of the container. In further embodiments, the source of penetrating

radiation includes an x-ray tube operating at a voltage in substantial excess of 200 kV, and may operate in a region of approximately 450 kV.

In a further embodiment, the invention provides a method, for producing an x-ray image of a large object, utilizing a device such as described above, along with an arrangement
5 for processing the signal from the signal output of the detector to form an image of the object.

In a further embodiment, the invention is a scatter image of an object. The image is formed by (a) providing a device such as described above, then (b) using the motorized drive to move the device past an object so as to cause the object to be scanned along two dimensions; and (c) processing the signal from the signal output of the detector to form an
10 image of the object. The object may, for example, be a motor vehicle having at least two pairs of wheels. The object may also, for example, be a trailer, a railroad car, a sea cargo container, an air cargo container, or a freight pallet.

Brief Description of the Drawings

15 The invention will more readily be understood by reference to the following description taken with the accompanying drawings, in which:

FIG. 1 is a plot of the x-ray interaction coefficients of two materials, heroin and iron, over the range of x-ray photon energies from 10 to 500 keV.

FIG. 2A is a perspective view of a device for inspecting a large container with
20 penetrating radiation in accordance with a preferred embodiment of the invention.

FIG. 2B is a side view of a further embodiment of a device for inspecting a large container with penetrating radiation in accordance with the invention.

Figure 3 is a top schematic view of the layout of the system shown in FIG. 2B, as configured for transport.

25 Figure 4 is a side elevation schematic view of the layout of the system shown in FIG. 2B.

FIG. 5A shows the cargo container inspection system of FIG. 2B, as deployed for inspection of a full-sized tractor-trailer.

FIG. 5B shows the cargo container inspection system of FIG. 2B, as deployed for inspection of a passenger van.

Detailed Description of Specific Embodiments

5 As used in this description and in the appended claims, a “cargo container” is a receptacle for the storage or transportation of goods, and includes freight pallets as well as vehicles, whether motorized or drawn, such as automobiles, the cab and trailer of a truck, railroad cars or ship-borne containers. The term “cargo container,” as used herein, further includes the structures and components of the receptacle.

10 The invention described herein serves to characterize materials which may be contained within a cargo container and thus not readily susceptible to visual scrutiny. The characteristics of a material which might be the object of non-invasive inspection and which lend themselves to detection using the device and method taught by the invention include, but are not limited to, electron density, atomic number, mass density, linear dimensions and
15 shape. These characteristics are unveiled by taking advantage of the various physical processes by which penetrating radiation interacts with matter. Penetrating radiation refers to electromagnetic radiation of sufficient energy per photon to penetrate materials of interest to a substantial and useful degree and include x-rays and more energetic forms of radiation. The interaction of such radiation with matter can generally be categorized as either scattering or
20 absorption processes. Both types of process remove x-ray photons from a collimated (i.e., directional) beam; scattering processes do so by deflecting photons into new directions (usually with loss of energy), while absorption processes simply remove photons from the beam.

25 Conventional transmission imaging measures the total beam attenuation as a function of position on the image plane, without discriminating between absorption and scattering processes. The total beam attenuation is described by a parameter called the mass attenuation coefficient, as commonly employed by persons skilled in the art of x-ray inspection. The mass attenuation coefficient is a characteristic of a particular material at a specific x-ray photon energy, and is independent of the imaging geometry. As such, it is the sum of

individual coefficients (or "cross sections") for each relevant physical process, each of which varies differently with x-ray energy and with the atomic number (Z) of the interacting material.

In the range of photon energies useful for penetrating and screening cargo containers, the scattering contribution is dominated by incoherent, or Compton scattering, and the absorption contribution is dominated by the photoelectric effect. The cross sections for Compton scattering and photoelectric absorption vary with both the atomic number of the material and with the energy of the x-ray photon, but in very different ways. The photoelectric absorption decreases very rapidly with increasing photon energy, and increases very rapidly with increasing Z of the material. The Compton scattering cross section changes very slowly with energy and is only weakly dependent on atomic number. These functional relationships are illustrated in Figure 1 for two relevant materials (iron and heroin). The Compton scattering cross section **10** for a low-Z material such as heroin and the Compton scattering cross section **12** for iron are nearly identical over the energy range of interest, and show little variation with energy. However, the photoelectric cross sections **14** and **16** are very different for the two materials, and both vary rapidly with energy. For heroin, the Compton scattering cross section **10** dominates the photoelectric cross section **14** for all x-ray energies above 20 keV. In contrast, for iron the photoelectric cross section **16** dominates for energies up to about 120 keV. Over the range from 60 keV to 400 keV, the total absorption coefficient (the sum of the Compton and the photoelectric coefficients) varies by less than a factor of two for heroin but by about a factor of 13 for iron. Such differences in scattering and absorption characteristics between low Z materials, characteristic of organic materials, and high Z materials, characteristic of most metals and their alloys, are typical and provide the means to differentiate between these two classes of materials.

Conventional transmission x-ray images simply provide a map of the attenuation characteristics of the inspected object for the full spectrum of the x-ray beam. It should be noted that images may be directly displayed in graphic format for the visual inspection of human operators, but need not be so displayed. As used in this description and in the appended claims, the term "image" refers to any multidimensional representation, whether in

tangible or otherwise perceptible form or otherwise, whereby a value of some characteristic is associated with each of a plurality of locations corresponding to dimensional coordinates of an object in physical space, though not necessarily mapped one-to-one thereonto. Thus, for example, the graphic display of the spatial distribution of some feature, such as atomic
 5 number, in one or more colors constitutes an image. So, also, does an array of numbers in a computer memory or holographic medium. Similarly, "imaging" refers to the rendering of a stated physical characteristic in terms of one or more images.

Backscatter imaging in which the x-rays scattered by a material in a generally backward direction are employed offers several unique inspection capabilities and operational
 10 features. (1) Taken alone, it is a one-sided imaging modality: images can be obtained even when the object is accessible from only one side, or, the object is too thick to be penetrated radiographically. (2) Because the scatter signal falls off quite rapidly with increasing depth into the object, backscatter images effectively represent a "slice" of the object characteristic of the side nearest to the x-ray source; this image is frequently useful even when a
 15 transmission image representing the same scanned area is hopelessly confused by image clutter. (3) The underlying physical phenomenon that leads to scattered radiation is the Compton effect. Low atomic number (low Z) materials, which encompass organic materials, interact with x-rays principally by Compton scattering. Narcotic drugs, being among the densest of organic materials, tend to produce the brightest signatures in a backscatter image,
 20 as do organic explosives, making backscatter imaging a useful imaging modality for bomb or drug detection. (4) Alignment requirements of the x-ray beam with detectors or collimation devices are less exacting than for transmission imaging thereby enabling rapid deployment in a wide range of inspection scenarios.

To the extent that Compton scattering removes x-ray photons from the x-ray beam, it
 25 contributes to the attenuation map image produced by transmitted x-rays. However, a scattered photon that is removed from one beam path projection and scattered into another contributes only an unwanted background or "fog" in the transmitted x-ray image. In cone-beam imaging geometries (e.g., film radiography), the scattered background can be a serious problem, and can, in fact, dominate over the transmitted x-ray image data.

It is known to persons skilled in the art of x-ray inspection that high-Z and low-Z materials may be separately identified by measuring total attenuation at two different photon energies. This is the basis for the dual-energy systems in widespread use for airport baggage inspection.

- 5 Another method to image low-Z materials is backscatter imaging. The technique relies upon the direct detection of photons which have been Compton scattered. An image is created that is separate and independent of any transmission image that may be produced at the same time. Since the photoelectric absorption cross section is small for organic materials, they interact almost entirely through Compton scattering, producing relatively large scatter
- 10 signatures. Metals, on the other hand, interact almost exclusively by photoelectric absorption, so that their scatter image signature is comparatively small. The backscatter image directly reveals organic materials such as drugs or explosives.

- Flying-spot technology makes possible the acquisition of images using detectors specifically positioned to collect the scattered x-rays. In a typical flying-spot system, a thin
- 15 "pencil beam" of x-rays is rapidly and repetitively swept through a source-centered, vertically-oriented "fan" of beam paths that are arranged to intercept the object under inspection. At the same time, the object is moved at a constant, slower speed along a path perpendicular to the fan, on a horizontally moving conveyor belt for example. In this way, the pencil beam is made to traverse the object in point-by-point raster fashion, and the entire
- 20 object is scanned as it passes through the fan plane over a period ranging from a few seconds to a few minutes depending upon the length of the object.

- Although the total scan time is seconds to minutes in duration, the actual exposure time of any part of the scanned object is only the time it takes for the pencil beam to sweep across that pixel. That exposure time is typically in the range of 8 to 64 microseconds,
- 25 depending on the design and the application, and yields an entrance exposure to the scanned object of only tens or hundreds of microroentgens. This low dose to the object also means that there is little radiation available to scatter into the environment, so the doses to operators and other bystanders is correspondingly low. Separate, large-area detectors are deployed adjacent to the beam plane on the x-ray source side of the scanned object, and with their

active surfaces oriented toward the scanned object. These detectors need only provide a large solid angle for collection of scattered radiation; no critical alignments are required. In this location these detectors respond to x-rays which are scattered generally back toward the source from the object.

5 Typically, the transmission x-ray signature of organic materials is relatively weak in comparison to that of higher density, higher atomic-number materials such as metals. Since the x-ray transmission image is a result of interactions throughout a path through the entire object, larger and more complex objects such as cargo containers produce more confusing transmission images. Under these circumstances, even the presence of small amounts of
10 metal and normal expected organic materials can produce extremely cluttered images masking the sought-for contraband. Image interpretation then becomes an overwhelming task. Frequently, most of the useful information is obtained from the backscatter image alone.

In a preferred embodiment of the present invention, the cargo container inspection device uses flying-spot x-ray imaging and backscatter imaging technologies. Equipment costs
15 can be reduced if backscatter imaging is used to the exclusion of other modes of x-ray interrogation of the contents of the cargo container.

Referring now to FIG. 2A, a perspective view is shown of a cargo container inspection system, designated generally by numeral **20**, in accordance with a preferred embodiment of the invention. Cargo container inspection system **20** is shown deployed for
20 inspection of passenger cars **22** and **23**. FIG. 2B shows a preferred embodiment of the invention. With reference to FIGS. 2A and 2B, a truck **24**, typically 35' long × 8' wide × 10'6" high, houses and supports the x-ray inspection equipment, ancillary support and analysis systems, and a hydraulic slow-speed drive mechanism to provide the scan motion. Truck **24** serves as both the platform on which the mobile system is transported to its intended
25 operating site, and a bi-directional translation stage, otherwise referred to herein as a "bed," to produce the relative motion required during a scan. Chopper **26** is used, in accordance with flying spot generation techniques known to persons skilled in the art, to scan beam **28** of penetrating radiation recursively in a vertical direction. Radiation scattered by the contents of the cargo container, shown here as passenger car **23**, is detected by x-ray backscatter detectors

30. Boom 32 allows beam stop 34 to track beam 28 as truck 24 advances in scanning past the cargo container. Beam stop 34 is also referred to as a "beam catcher." In addition or alternatively to beam stop 34, an x-ray transmission detector may be mounted in opposition to beam 28, tracking beam 28 on the distal side of the scanned cargo container.

5 Referring now to FIG. 3, a top schematic view of the layout of the system shown in FIG. 2B, is depicted as configured for transport. FIG. 4 is the corresponding side elevation, additionally showing the detectors in one of two available deployed positions. The modular components comprising the cargo container inspection system are: the penetrating radiation source assembly 40; x-ray high voltage generating subsystem including high voltage power supply 42 and high voltage tanks 44; backscatter detector modules 30, comprised of an upper
10 bank 46 of detectors and a lower bank 48 of detectors; detector electronics module 50; and operator's console 52. The dashed position of upper backscatter detector banks 46 indicate the position for inspection of cargo containers. The x-ray source 40, high-voltage power supply 42, and positive and negative high-voltage tanks 44, are all in accordance with ordinary
15 practice in the art of x-ray generation. In a preferred embodiment of the invention, a 450 kV x-ray tube is employed.

FIG. 5A shows a cargo container inspection system 20, in accordance with a preferred embodiment of the invention, as deployed for inspection of a full-sized tractor-trailer 60 while FIG. 5B shows the same cargo container inspection system 20 deployed for inspection
20 of a passenger van 62. The angle of elevation 64 of the 43° scanning beam can be changed depending upon the application. For optimum versatility, the range of limiting angles extends from at least 55° below horizontal to 55° above horizontal. This corresponds to an angular adjustment of the source axis from -33.5° to +33.5°.

Operationally, one side of a large truck 60 (up to 14' height), as depicted in FIG. 5A,
25 can be completely covered in three passes; however, in many cases, satisfactory coverage can be achieved in two passes. The system operators must choose between doing a third pass or tolerating a small amount of corner cutoff 66, in which case, higher inspection throughput can be achieved. Since the scanning system is bi-directional, alternate passes can be in the forward and reverse directions.

Operationally, one-side of passenger cars and small trucks is scanned in a single pass of the system. Depending upon the situation, it may be necessary to scan the opposite side as well. The upper set **46** of backscatter detectors can be deployed over the top of smaller vehicles as shown in FIG. 5B, substantially improving the scatter collection efficiency and
5 producing higher quality images. Backscatter detector modules **46** and **48**, two are typically 6' long and 1' wide, and each typically comprises four segments.

In a preferred embodiment of the invention, the cargo container inspection system has two scan-speed modes: nominally 3 inches/sec and 6 inches/sec. The faster speed results in higher throughput, the slower mode - higher image quality. In accordance with one
10 embodiment of the invention, image data in either mode is acquired into a 1024 x 4096 x 12 bit image memory and displayed onto a 1024 x 1024 high-resolution display via a continuously-adjustable 12-bit-to-8-bit look-up table. Additional displays can be provided to allow simultaneous viewing of more than one image, or, alternatively, images may be superposed or combined, as known to persons skilled in the art.

15 Backscatter detectors are mounted to allow efficient collection of scattered radiation from close to the road surface, all the way to the roof of the inspected container. A motorized mechanism enables the upper set of detectors to be deployed over a small vehicle, as shown in Figure 5B, though other means of deployment are readily apparent to persons skilled in the mechanical arts and are within the scope of the invention.

20 The operator's console **52** (shown in FIG. 3), provides for the console operator to control the x-ray system and display images. Various display monitors may be provided. One preferred embodiment has an upper display for transmission images, and a lower display for the corresponding backscatter image. Similarly, various display functions may be provided:

- Zoom, pan and scroll - Joystick controls allow the operator to display any part of the
25 image at 2x and 4x magnifications.

- Continuous density expand - This contrast-enhancing feature allows the operator to display any contiguous subset of the 12-bits (4096 digital intensity levels) of image data over the full black-to-white range of grey levels on the display monitors. The implementation is through a set of 10 pre-set push buttons, along with a trackball for fine-tuning.

• Edge enhancement - A mathematical algorithm sharpens the image and extends the effective dynamic range of the display for faster and easier image analysis.

• Reverse video - Operators may select between positive (black-on-white) or negative (white-on-black) image display, depending on personal preference.

- 5 • Image archiving - Operators may "mark and annotate" the images from the console keyboard, and store them on optical disk for future recall.

Truck **24** containing cargo container inspection system **20** is fitted with a custom-built box (or truck body) **68** (shown in FIGS. 5A and 5B) specified to accommodate the imaging equipment, and to provide support structures, environmental control, and electrical power
10 distribution.

Truck **24** is provided with both front- and rear-wheel drive: Standard rear-wheel drive from the truck's engine is used for normal over-the-road travel. An alternative drive mode is powered by a low-RPM hydraulic motor to obtain the very low speeds employed for the scan. The two drives are connected via a switchable gearbox to preclude the possibility of having
15 both active at the same time. The hydraulic motor controls, including speed selection, drive direction, and motion start/stop, are located in the cab of the truck under the control of the driver. As an additional safety feature, actuation of the truck's brake will automatically cause disengagement of the hydraulic clutch. A similar arrangement using a hydraulically-powered front or rear wheel drive is known in the art for other special applications requiring very slow
20 vehicle motion.

Deployable beam stop **34** is employed to assure compliance with FDA radiation safety requirements. However, the output radiation of the system is so low that the health and safety requirements for low radiation levels is met only a few feet away from the source even if no beam stop is used. Beam stop **34** uses a dense shielding material such as lead that is deployed
25 from the end of a boom **32** that extends about 14' from the side of truck **24** at the location of the x-ray beam **28**. Generation of x-rays is prevented by interlock circuits unless boom **32** and beam stop **34** are properly deployed.

To stow the beam stop for road travel, the beam stop is retracted into the hollow boom **32**. Boom **32** is then rotated parallel to the truck axis and lowered into a cradle in truck box **68**.

The scan motion is exceedingly slow - 1/3 to 1/6 of a mile per hour . An audible alarm
5 is actuated whenever the scan drive mechanism is engaged for motion in either direction.
Since this motion also coincides with x-ray generation, the audible warning also provides an
"X-RAYS ON" warning. The x-ray high voltage power supply **42** is interlocked so that it
cannot be energized unless both chopper wheel **26** is up to speed and truck **24** is in motion.
This additional safety precaution ensures that the scanning beam will not be stationary over
10 any one region of space for a long time, thus ensuring low delivered dose.

Operation will be described as it applies to the inspection of one or more passenger
cars; scanning of large vehicles will be similar, except that the upper detectors do not need to
be swung outboard in this case. It will also be assumed that the system will first be set up,
and that vehicles to be scanned will then be brought to it. An alternative whereby the system
15 is deployed beside parked vehicles or containers calls for a minor variation of procedures.

Upon arrival at the intended inspection site, the operators will first assure that the site
is suitable: i.e., that there is a sufficient space available for system operation and that
operating space can reasonably be secured for safe operations. They will then position the
truck at the starting position for the first scan, assuring that there is sufficient room to move
20 the truck ahead for the required scan distance, usually about 65 feet. (Scans will normally
alternate, forward and back; it is also possible to scan sequentially in the forward direction
only, to scan a continuous line of parked vehicles for example, provided that the necessary
space is free.) Once positioned, the on-board generator is started to provide power for system
operation, lighting, and a cooling unit. Operator's console **52** is powered up at this time.

25 The operators then manually deploy the backscatter detectors and the beam stop using
a motorized mechanism provided for that purpose. Only the upper set of detectors **46** deploy,
as shown in FIG. 5B. The beam stop is deployed by rotating the boom into a position
orthogonal to the truck, and then lowering the beam stop out of the boom to its preset limit.

This action closes an interlock circuit that is required before x-ray generation is possible. An x-ray tube warm-up sequence , if necessary, is then initiated from operator console 52.

Following warmup, the physical configuration of the system setup is completed by rotating the x-ray beam angle to the direction (elevation) required for the intended scan operations. This is done by a manually-actuated electric motor, and with the aid of an indicator gauge to assist in setting the desired scan elevation. Scanning operations can then commence.

Scan operations are simple and straightforward. One or more vehicles are directed to positions along the scan path (up to 65 feet of total vehicle length may be imaged in a single scan) and the drivers and passengers exit the vehicles.

Using menu-driven software, the system's computer is readied for image acquisition. This places the computer and data acquisition electronics into a status wherein c-rays will be initiated and image acquisition started upon receipt of a "scan" command initiated by the system's slow-speed drive controls. The computer also transmits a "ready" status signal to the scan drive control located next to the driver of truck 24.

The driver sets the desired scan speed and direction at the scan drive control. After the "ready" status is received from the computer, the driver starts the scan by pushing a "start" button and releasing the truck brakes. "Start" initiates motion via the slow-speed drive. The driver has continuous control over the truck. He is responsible for steering, and may stop the truck at any time by actuating the brake. Otherwise, the scan will stop automatically after a full data set has been acquired by the computer (and the "ready" status is removed).

As soon as the truck is in motion, a "scan" signal is sent to the computer. The computer then triggers the x-ray generator to ramp up to its pre-set operating conditions, and upon confirmation that they have been reached (about 5 seconds later) it starts data acquisition. Data acquisition continues until either the "scan" command is interrupted or the image memory is full.

To break the system down for transportation, electronic systems are shut down and the beam stop and detector mechanisms are retracted and secured for travel. The hydraulic drive is disengaged and its power shut off. The generator is switched off.

In a further embodiment, preferred in various applications, the intensity of the transmitted x-ray beam may be measured by a single, elongated transmission detector located on the opposite side of the inspected object from the x-ray source and carefully aligned with the plane of the x-ray beam. The detector is designed to accept and respond to x-rays striking
5 anywhere along the length of its linear entrance slit. The detector is oriented so that the flying-spot beam sweeps repetitively from end-to-end along the slit while truck 24 moves past the inspected object. The detected signal is amplified, integrated, sampled and digitized into an image memory over many sequential, short time intervals during each sweep of the pencil beam. Each such digitized sample forms one pixel of the final image, and the series of
10 samples acquired during one sweep of the beam constitutes one line of image data - typically 1024 samples per line. A complete image frame is constructed by acquiring successive lines as the object is moved through the scan plane.

In the flying beam mode, the positional image information is acquired by correlating the instantaneous detector output with the position of the flying-spot beam at that instant of
15 time. In a corresponding "fanbeam" system an entire line is illuminated at once and individual pixels along the line are acquired either by a large number of discrete detectors arranged along the line, or one or more detectors with positional sensitivity. The transmission detector may comprise scintillators optically coupled to photomultiplier tubes. This method is more efficient and less noisy than using a photodiode array. The resulting
20 improvement in signal/noise allows equivalent images to be made at lower doses and with lower beam energies.

The described embodiments of the invention are intended to be merely exemplary and numerous variations and modifications will be apparent to those skilled in the art. All such variations and modifications are intended to be within the scope of the present invention as
25 defined in the appended claims.

What is claimed is:

1. A device, for inspecting a cargo container with penetrating radiation, the device comprising:

- 5 (a.) a bed moveable along a first direction having a horizontal component;
- (b.) a source of penetrating radiation, mounted on the bed, for providing a beam having a predominantly horizontal component;
- (c.) a motorized drive for moving the bed in the first direction;
- 10 (d.) at least one detector mounted on the bed, each detector having a signal output;

so that the beam is caused to traverse the cargo container as the bed is moved and each detector provides a signal for characterizing the cargo container and any contents of the cargo container.

15

Abstract

A device for inspecting a cargo container such as a motor vehicle or freight pallet, with penetrating radiation. A source of penetrating radiation is mounted on a moveable bed, 5 thereby allowing a beam of penetrating radiation to sweep the large container. At least one detector is also mounted on the bed, either on the side of the source or on a boom, so that, as the beam is scanned across the container, the container and any contents of the container are characterized by transmitted or scattered radiation, or both.

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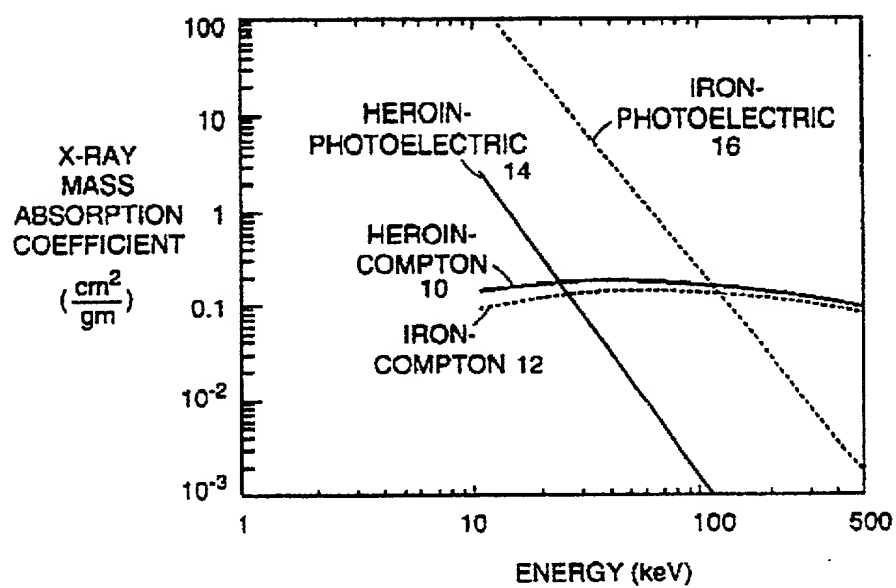


FIG. 1

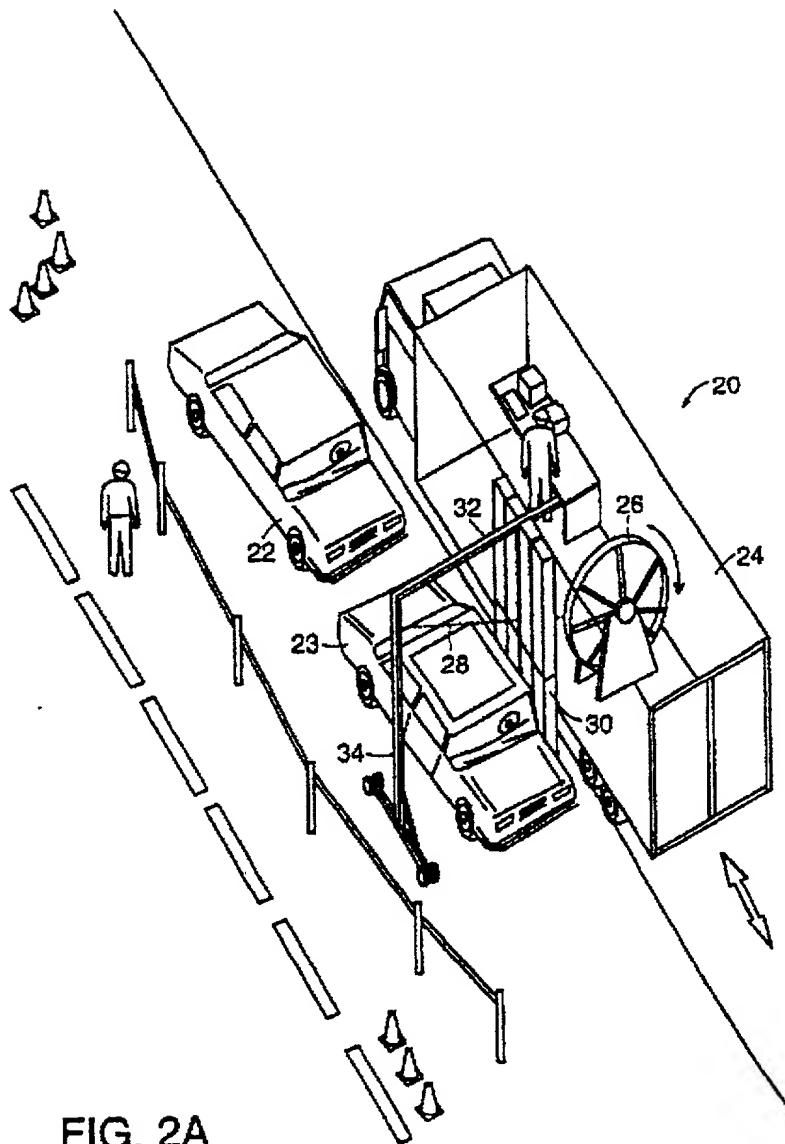


FIG. 2A

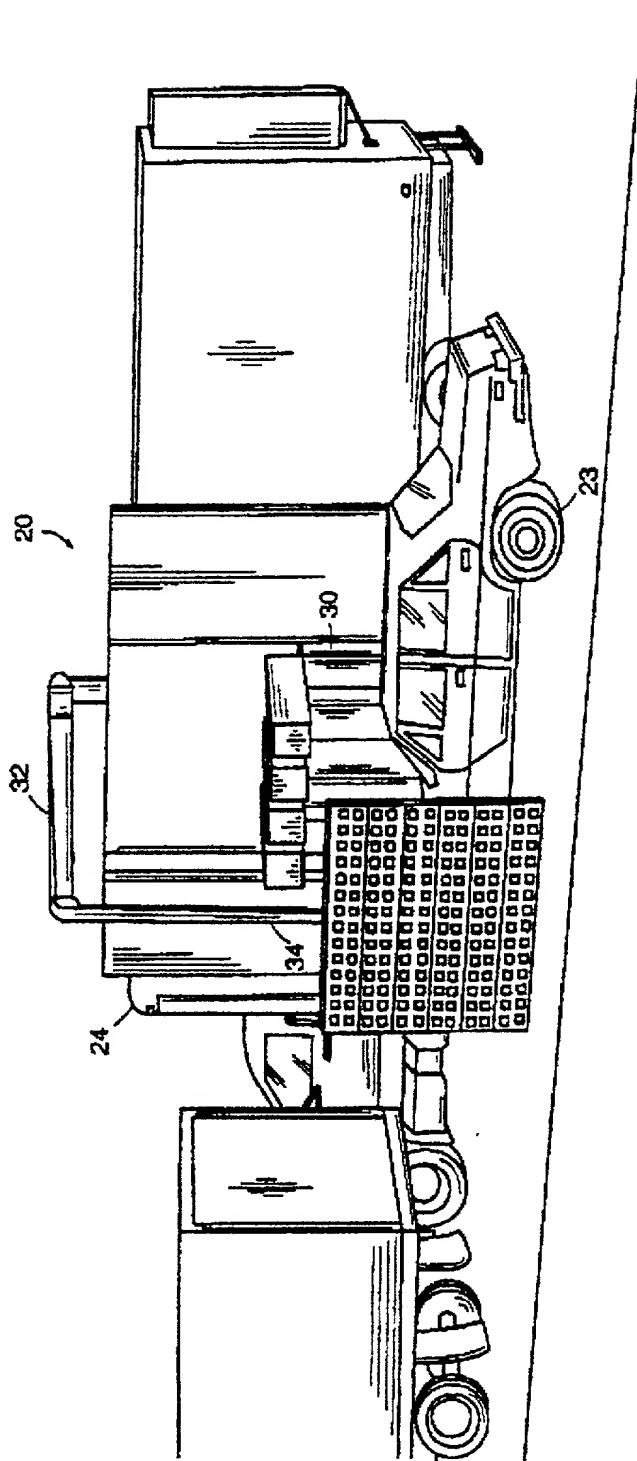


FIG. 2B

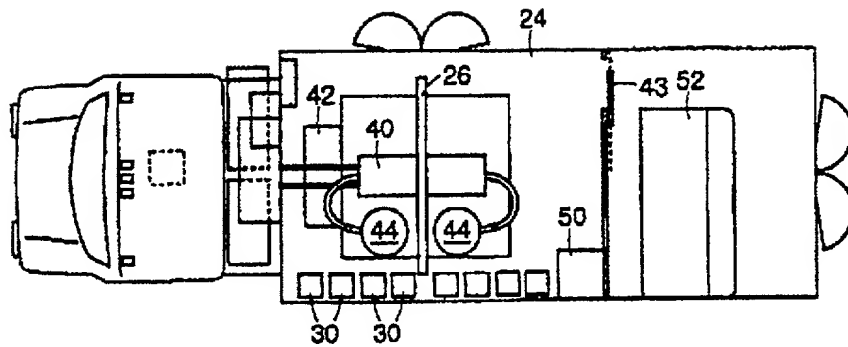


FIG. 3

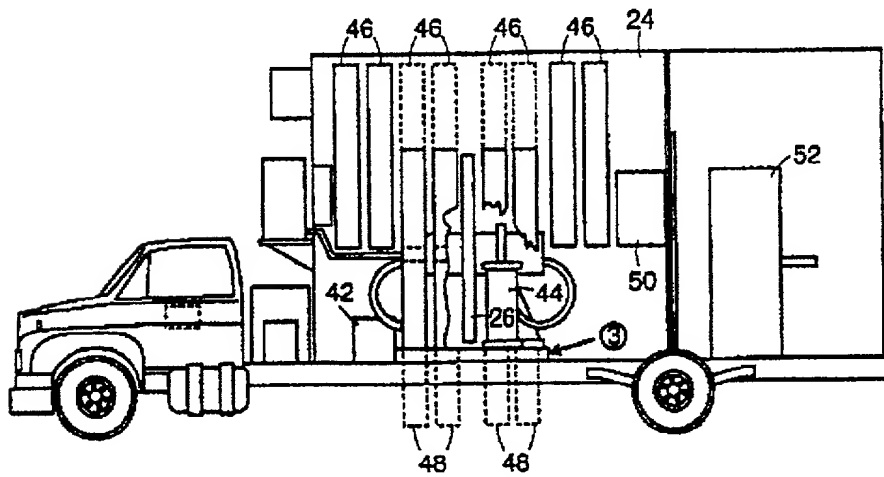


FIG. 4

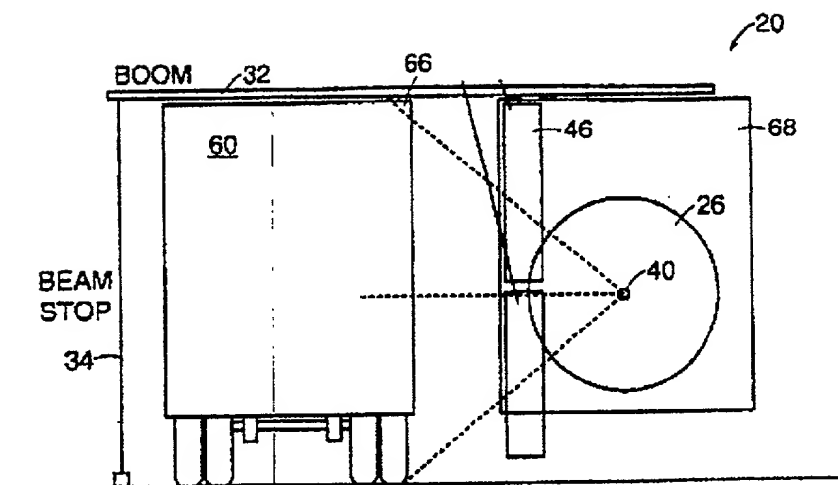


FIG. 5A

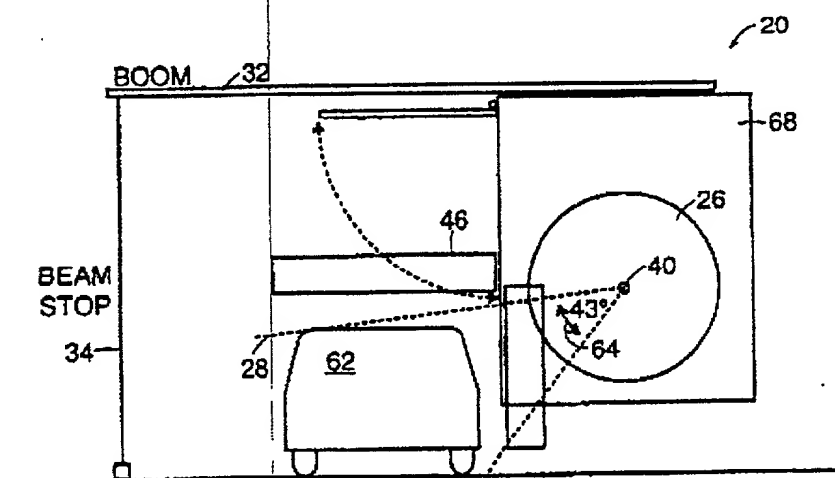


FIG. 5B

665050-27490660

Docket-No.

1945/157

Declaration and Power of Attorney For Patent Application

English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

MOBILE X-RAY INSPECTION SYSTEM FOR LARGE OBJECTS

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on February 12, 1997 as United States Application No. or PCT International Application Number 08/799,533

and was amended on _____

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Not Claimed

(Number) (Country) (Day/Month/Year Filed)

☐

(Number) (Country) (Day/Month/Year Filed)

☐

(Number) (Country) (Day/Month/Year Filed)

☐

hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

(Application Serial No.)

(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112. I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

(Application Serial No.)

(Filing Date)

(Status)
(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

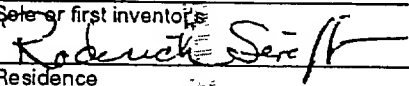
POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (list name and registration number)

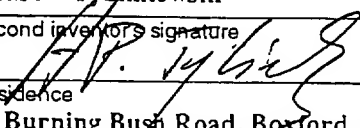
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